SUSTAINABLE BIOMASS ENERGY PROGRAM

NREL LOI — Hawaii Project

FINAL REPORT

Prepared by
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EXECUTIVE SUMMARY

The decline of the sugar industry and closing of plantations and mills made large tracts of land and infrastructure available for the planting and evaluation of selected crops. Warm temperatures and abundant sunlight create an environment that is almost ideal for the cultivation of biomass crops that might serve as dedicated feedstocks for the production of energy related products.

The project team that was established to develop this effort provided expertise and knowledge in the areas that are considered essential to evaluate this opportunity. The team consisted of the Pacific International Center for High Technology Research (PICHTR), Amoco Corporation, Cargill Incorporated, C. Brewer and Company Ltd., Hawaii Electric Light Company (HELCO), Hawaiian Electric Company (HECO), the County of Hawaii, and the Hawaii State Department of Business Economic Development and Tourism (DBEDT).

The site chosen for the "Biomass Systems Integration Program" (Hawaii LOI) was the 13,000 acre Ka'u plantation on the Island of Hawaii. The plantation and Sugar Mill are owned by C. Brewer and Company Ltd. The primary focus of the Hawaii LOI was utilization of the sugar crop or other crops with sufficient carbohydrate content to produce ethanol and electricity. The primary objective of the program was to determine if an investment worthy business could be based on the conversion of a dedicated feed stock to ethanol and electricity. The question was approached in two parts:

1) Evaluation of crops that might be used as feedstocks for the production process.

2) Evaluation of the performance of technologies for the conversion of feed stock to ethanol and by-products.

The approach used in completing the evaluation was as follows:

- Candidate crops were evaluated to determine the yields, cost of production, and composition of the most promising crops.
- The delivered crop cost information was used as an input in a general evaluation of technologies for converting lignocellulosic crop biomass to ethanol.
- Technologies that appeared to hold promise of producing ethanol and by-products were given preliminary evaluation. The technologies that produced products at the least cost were selected for more detailed analysis.
- A comprehensive model for a commercial scale plant was developed, based on the most promising technology.
- This model was used to conduct an analysis of the performance of the system, using the selected crop(s).

- The information from the detailed evaluations was used to produce a standard financial analysis.

The sources of biomass evaluated included sugar cane, energy cane, sorghum, napier grass, and the tree crops Leucaena and Eucalyptus. The focus of the analysis was to identify a crop or crops with appropriate characteristics to be used as a feed stock for the production process, and to determine if it could be supplied at a cost that was consistent with providing the final product(s) to the market at a profit. The results of a preliminary economic overview indicated, on the basis of yield per acre per year and projected production costs, that energy cane and napier grass were the most promising biomass crops. A detailed analysis of the cost of production of these crops at the Ka'u site was completed.

A production regime that would allow energy cane to be planted and harvested on an 18 month cycle was used. Projections for the 13,200 acre site at Ka'u indicated that the yield of energy cane would average 125 whole wet tons per harvested acre and could be delivered to the conversion facility for approximately 42 per bone dry ton. A similar approach indicated that napier grass could be delivered to the conversion facility for approximately 28 per bone dry tone. These numbers were used as the cost of dedicated biomass in the conversion facility economic feasibility analysis (see Table VII-2, pg 98).

A comparison of technologies for conversion of biomass to ethanol and electricity was carried out along the same lines. Promising technologies were reviewed in a preliminary fashion. The most promising approaches were surveyed in detail, using the costs and operational considerations for the Ka'u site. The technologies evaluated included: simultaneous saccharification and fermentation (SSF); concentrated acid hydrolysis, neutralization and fermentation; and concentrated acid hydrolysis with acid recycle and fermentation. A summary of the comparative evaluation is presented below:

Preliminary Capital and Process Comparison

	Energy cane @ $42.11/dry ton 25 million gallons /year			Napier grass @ $28.00/ dry ton 25 million gallons /year		
PROCESS	CAPITAL (million $)	$/gallon ethanol	Biomass tons/day	CAPITAL (million $)	$/gallon ethanol	Biomass tons/day
1. Simultaneous saccharification and fermentation	$81 .3	$1.06	979	$81.3	$1.03	1,389
2. Concentrated acid hydrolysis, neutralization and fermentation	$99.3	$1.77	1,136	$99.3	$1.73	1,612
3. Concentrated acid hydrolysis, acid recycle and fermentation	$71.7	$1.49	994	$71.7	$1.45	1,411

Note: Separate Hydrolysis of Fermentation (SHF) was also evaluted. However due to previous analysis, lower yields and higher costs than SSF lead to early elimination (p. 97).

Other options for biomass conversion that were evaluated involved milling and squeezing energy cane to remove the sugar containing juice that would be fermented directly to produce ethanol and burning the remaining bagasse to produce process heat and electricity. Also considered was the cultivation of napier grass for direct combustion to produce electricity. The energy cane option resulted in an annual loss on operating of about $3.4 million. The napier grass combustion analysis indicated that this proposed business was also unprofitable. In this case, the cost of the biomass alone exceeded the value of the electricity and the capacity payments.

The results of the preliminary evaluations indicated that Simultaneous Saccharification and Fermentation (SSF) justified further analysis. Amoco Corporation had selected this technology to be evaluated at in a pilot plant constructed in Ontario, Canada. This technology is referred to as the Amoco/ NREL SSF system. The characteristics and delivered costs of biomass were used as inputs to the system. Samples of biomass from Hawaii were processed in the pilot plant. Based on the substantial amount of detail developed by Amoco the cost and operational performance of the plant were used to provide the basis for a new and comprehensive evaluation. The analysis projected the capital and operating costs based on throughput of specified amounts of dry biomass per day. This more detailed analysis showed less promising results than the initial evaluation.

Energy cane processed at 1,270 tons per day produced projected revenues from sale of ethanol and electricity, including capacity payments, of $74.5 million per year. Biomass, chemicals and labor were the primary variable costs, totaling $52.7 million per year. The total annual costs ranged from $78.4 million in year two to $55.8 million in the fifteenth year. Positive cash flow was achieved in the third year with pre tax net profits averaging $11.4 million per year. Over a period of 15 years, the accumulation of after tax profits was only $25 million. This was insufficient to pay back the $160 million required to establish the facility in a timely fashion and did not provide a basis for an investment worthy business. When napier grass was used as the feed stock, the projected revenues were $51.8 million per year. By the fifteenth year the accumulated profits were barely $5 million. This was not enough to pay off the investment.

It is reemphasized that this project was limited to in-depth evaluation of dedicated feedstocks at a specific site within the context of existing sugarcane growing operations and focused specifically on the production of fuel grade ethanol and dispatchable electricity. Although a significant number (15) of promising feedstocks were evaluated, this study was by no means exhaustion and the detailed economic analysis of six (6) crops for the Ka'u site should not be construed as definitive for all sites and crops on the Island of Hawaii. Furthermore, the study chose the conservative economic analysis approach of not including tax credits and other kinds of stats other federal economic assistance.[1] While C. Brewer was not willing to operate the mill through the 3-4 year period required to complete the permits, build a pre-commercial demonstration facility, and conduct performance evaluations that would be required for a successful commercial venture, the program was able to interest Arkenol, a company that has developed biomass/ethanol technology, in pursuing this opportunity. Arkenol has recently been acquired by Tenneco, and as a result has the financial capacity to develop the commercial scale business. They have conducted an independent analysis of performance of their "Concentrated Acid Hydrolysis and Recycle" technology using napier grass as the feed stock and have concluded that there is an economic basis to proceed with the development of a commercial venture at this time.

Hydrolysis and Recycle" technology using napier grass as the feed stock and have concluded that there is an economic basis to proceed with the development of a commercial venture at this time.

Continuing support from county, state, and federal agencies will be critical to Arkenol/Tenneco as they seek ways to reduce the capital risks associated with the development of an emerging technology of this nature. Should Arkenol/Tenneco continue to be successful in putting together the necessary components required for economically and environmentally sustainable business, it is the opinion of this project that the community and State of Hawaii will receive long-term benefits as a result of their participation and support.

SECTION 1 — BACKGROUND

The objective of this program was:

"To determine if there was an investment worthy business based on the conversion of a dedicated feedstock to ethanol and electricity."

All of the tasks in this report were structured to provide the inputs to answer this question. The natural conditions that exist in Hawaii and a combination of events that have taken place in recent years provided the foundations for the proposed project. These included:

- The decline of the sugar industry and closing of plantations and mills. The crisis created by these events makes available large tracts of land and infrastructure for planting and evaluation of selected crops. This land may be appropriate to the production of biomass to be used as dedicated feedstock supply systems (DFSS) for the production of ethanol and/or as a combustion fuel for generating electricity. A labor pool of individuals skilled in growing, harvesting, and delivering crops to the processing plant is now available due to this decline.
- The State of Hawaii currently imports oil to meet 90% of its energy needs. This dependence on imported energy has generated great concern and resulted in a state policy favoring the development of indigenous resources for the production of transportation fuels and electricity.
- Regional demand for electrical generating capacity placed an emphasis on augmenting the power supply and stimulated the interest of the utilities in the development of electricity from sustained sources of biomass. Biomass (bagasse) has been burned to supply fuel for 22% of the electricity production on the island of Hawaii. Reductions in sugarcane acreage and the closing of the associated mills have also reduced the amount of bagasse available for the production of electricity and created a need for alternative fuel sources.
- The warm temperature and sunlight establish an environment that is almost ideal for the cultivation of several biomass crops that are appropriate for DFSS. The year around growing season also allows continuous crop harvesting, makes efficient utilization of personnel and equipment, and eliminates the need for prolonged storage of the harvested crops.

The Organization

The Project Team that was established to develop this effort consisted of Pacific International Center for High Technology Research (PICHTR); Amoco Corporation; Cargill; C. Brewer & Company, Ltd.; Hawaii Electric Light Company, Ltd. (HELCO); Hawaiian Electric Company (HECO); Hawaii Natural Energy Institute (HNEI); College of Tropical Agriculture and Human Resources (CTAHR); Hawaiian Sugar Planters' Association (HSPA); County of Hawaii; and State of Hawaii, Department of Business, Economic Development and Tourism (DBEDT). This group provided the expertise and knowledge in the areas that were considered essential to develop the project.

SECTION 2 — APPROACH

The site chosen for the "Biomass Systems Integration Program" was the 13,200 acre Ka'u plantation on the island of Hawaii. The plantation and sugar mill are owned by C. Brewer and Company, Ltd. The primary focus of the Hawaii LOI was utilization of the sugar crop or other crops with sufficient carbohydrate content to produce ethanol and electricity. The objective was to determine if there was an available technology for the conversion of lignocellulosic biomass to primary products that would result in a profitable business. The question was approached in two parts:

1) evaluation of crops that might be used as feedstocks for the production process (Task 3); and

2) evaluation of the performance of technologies for the conversion of feedstock to ethanol and by products (Task 4).

The sources of biomass to be evaluated included sugarcane, sorghum, napier grass, and the tree crops Leucaena and Eucalyptus. The focus of the analyses was to identify crop(s) with appropriate characteristics to be used as a feedstock for the production process and to determine if it could be supplied at a cost that was consistent with providing the final product(s) to the market at a profit. The crop analyses (Chapter II) were conducted at two levels: 1) a general review to identify the crop(s) with the most desirable characteristics and potential to be used as a dedicated feedstock; and 2) in-depth site specific economic analysis of the performance of the most promising crop(s) at the Ka'u site. The first level of analysis provided general information, but was not specific for any site. The results of a preliminary economic overview indicated, on the basis of yield per acre per year and projected production costs, that energy cane and napier grass were the most promising biomass crops. Detailed analyses of the cost of production of these crops at the Ka'u site were completed.

With the goal of achieving the highest efficiency of biomass utilization possible, a comparison of technologies for conversion of biomass to ethanol and electricity was conducted. The technology evaluation (Chapter III) was carried out along the same lines. Promising technologies were reviewed in a preliminary fashion. The most promising approaches were surveyed in detail, based on costs and operational considerations at the Ka'u site. The approach used in comparison of technologies was as follows :

- information from Chapter III - Crop Assessment was used to specify the yields, cost of production, and composition of the most promising crops;
- the delivered crop cost information was used as an input in a general evaluation of technologies for converting lignocellulosic crop biomass to ethanol;
- the technology that appeared to provide the most promise for producing ethanol and by-products at the least cost was selected for detailed analysis;
- a comprehensive model for a commercial scale plant based on the most promising technology was developed;

- this model was used to conduct an analysis of the performance of the system using the selected crop(s); and
- the information from the detailed evaluations was used to produce a standard financial analysis.